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STANDARDIZED TESTING PROTOCOL FOR EVALUATION OF EXPEDIENT FLOODFIGHT STRUCTURES

By

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1.0 Introduction

The primary purpose for developing this protocol is to test and evaluate the effectiveness of various types of expedient flood-fighting devices. Vendors of a wide range of commercial expedient structures are competing for U.S. Army Corps of Engineers emergency flood-fighting funds. These structures vary widely in form and function. For the most part, the only technical literature available on the products comes from the vendors themselves. Few vendors have tested their products at established laboratories; the majority bases their performance expectations on results of their own testing. Some vendors promote products that are conceptual or in prototype development stage only. Financial decision-makers within Federal, State, and Local government agencies responsible for flood fighting are the primary targets-of-opportunity for these vendors. The fundamental problem faced by these decision-makers is that they have no basis for substantiation of the claims made by these vendors. A Standardized Testing Protocol (STP) developed, administered, and executed by the US Army Corps of Engineers, Engineer Research and Development Center (ERDC) laboratories is a logical and necessary tool for providing unbiased, objective technical performance data. In order to participate in the testing program, the vendors of the various products will supply funding, materials, equipment and labor to assemble their systems in accordance with the STP, and in accordance with a Testing Services Agreement (TSA) to be executed between each vendor and ERDC.

The STP focuses on configuring expedient structures as a wall or impoundment within one of the Coastal and Hydraulics Laboratory’s Wave Basins (Attachment 1). Several key performance factors will be evaluated using STP guidelines. Structures will be subjected to hydrostatic loads, wave-induced dynamic loads, impact loads and overtopping, with the response of the structure to each test mode evaluated. Using this STP, a variety of expedient structures may be tested under the same set of controlled conditions. The results of the tests will allow the end user to determine applicability, benefits, and product performance for various situations.

In addition to performance factors, several operational factors will be measured and recorded. Included in the operational factors are man-hours required to construct and remove the test structure, special equipment or tools required, fill materials (if any), structure footprint, and suitability for construction by untrained labor. Suitability of the structure for use on uneven or sloping ground, different types of substrate, and with bends or curves will be considered.

2.0 Classes of Expedient Structures

The range and diversity of products used or intended for expedient flood-fighting is quite large. Products can be classified several ways. We have chosen to categorize these products into three major types:

A) Permanent
B) Semi-permanent
C) Temporary

Because of the size and high cost associated with modeling permanent and semi-permanent flood fighting systems, only temporary flood fighting devices will be tested under this program. The Temporary Structures may be further classified as:

- C-i Commercially available products that are complete flood fighting systems in and of themselves (e.g.: water-filled, air-filled, soil-and-sand-filled bladders, cells, or geo-textiles; Jersey Barriers; steel and concrete foldable barriers).
- C-ii Systems that are composed of readily available materials without a single sponsor marketing and selling the complete systems (e.g.: sand bags, mud boxes, fabric fold-back walls, plywood or planking flashboards with or without earth backing).

It may be difficult to identify a sponsor for type “C-ii”, classified systems since no one company may market the complete systems. However, if the method is assigned a high priority by the selection committee consisting of representatives from District offices and other federal agencies, testing will likely be performed at government expense.

3.0 Selection Criteria

At present there are a variety of products available or entering the market for expedient flood fighting structures. The selection committee will invite and query vendors as to their interest in participation in the testing program. Time and labor constraint will not permit testing of every available product. In order to qualify for the testing the vendor should:

a) Provide an analytical study of the "structural integrity" of the product under flood loading. The functionality must be supported by sound engineering and physics principles. As a minimum, calculations should be provided for sliding, uplift, overturning, required tie down configuration per unit length of structure, and stake pull out strength. All of the above should be calculated for static, dynamic impact and wave conditions.

b) Provide the cost per 100 feet of flood-fighting product, including tie downs, stakes, geo-textiles, membranes, sandbags, and other associated materials as required for an in- place system of a typical height placed on soil, rock, and concrete surfaces. Include an estimate of installation man-hours required per 100 feet of flood-fight product.

c) Provide list of materials, tools, and construction sketch needed to build the flood-fight structure, including tie downs or other anchors and how this will be performed in soils, concrete and asphalt concrete foundations.

d) Complete description of procedures for construction of the flood fight system, with detailed information including, but not limited to, the basic unit assembly, connection of individual units, description of all anchors, tie downs, strapping, etc., to form the complete system.

e) Provide accurate information to address environmental concerns for the product in the unused state, and also provide information on any environmental issues related to the product after it is used and potentially contaminated by floodwater (i.e. procedures for disposal of a potentially contaminated flood-fight structure). Explain in detail how the unit is to be taken apart and stored. If the unit is filled with a material (gas, liquid, semisolid, or solid), explain how to handle and dispose of these materials (at a minimum, Material Safety Data Sheets, as appropriate), to include procedures for disposal or treatment should they become contaminated.

f) Supply an adequate amount of the complete system product for model testing. Water depths ranging from approximately 2 feet to 3.75 feet will be used to test all flood-fighting products.
g) Provide consultation support during the testing of the product and provide assistance as requested by ERDC.
h) Agree to construct/install the candidate flood-fighting device at ERDC testing facility in Vicksburg, MS.
i) Assure that the structure (as constructed by the vendor or their representative in the ERDC test facility) meets the vendors' standard of construction.
j) Agree to accept results and allow publication by ERDC of test results. Results will be placed on a publicly-accessible webpage developed by ERDC and accessible to anyone, both government and private.

Once the evaluation committee selects products from all the candidates, the next step will be establishment of a Testing Services Agreement (TSA) with each vendor.

4.0 Standardized Testing Protocol

The STP utilizes a physical model testing facility to subject the expedient flood-fighting structures to loading similar to that found in a real flood situation. One important facet of the STP is to establish a baseline of performance for comparing the effectiveness of the new products. The integrity of the new products will be evaluated against the performance of a sandbag levee built according to typical COE guidelines. The STP will include documentation of construction requirements, material costs, labor, hydraulic performance, environmentally acceptable materials, and structural integrity of the baseline case as well as each product tested.

The following elements form the basis of the STP:

- The base (floor) for the Innovative Flood-Fighting Structures (IFFS) to be tested will be constructed in the area shown in Attachment 1. Each IFFS structure will be configured as an approximately 30 ft-long levee with two additional 10 ft- long levees at each end of, and at right angles to, the 30 ft long levee. The two 10 ft long levees will perpendicularly abut the concrete wing walls of the testing section. The IFFS will be constructed to between two and 3.75 foot high.
- The IFFS base must fit within the construction base area. Additional membranes used for seepage reduction and an occasional sandbags used as membrane hold-downs may be used in the pool area simulating the floodwater side of the IFFS. No IFFS structure parts, sandbags or membranes will be allowed inside the “off-limit” area shown in Attachment 1.
- Structures will be subjected to hydrostatic loads from incrementally increasing floodwater head, or depth.
- Structures will be subjected to hydrodynamic loads by applying waves of incrementally increasing height.
- Structures will be subjected to steady-state overtopping at 100% of IFFS height plus 1 inch or less, as governed by the maximum pumping capacity available to recirculate the overtopping water into the test basin.
- Structures will be subjected to a prototypical impact log test.
- Measurements of seepage and movement of IFFS will be made during all phases of the testing.
- Observations of movement of IFFS, fatigue or structural deterioration will be made during all phases of the testing.
- Up to three relatively small-scale repairs of documented damage are allowed during a test series.

5.0 Constructability Evaluation

Vendors will construct and install their own product at the ERDC test facility in Vicksburg, MS. The construction process will be recorded using a video camera. These tapes may be used later as part of Corps flood-fight training material. The first evaluation of the STP deals with issues of construction. Documentation and evaluation will be made of specific constructability issues. These issues include:

a) Manpower requirements

b) Foundation requirements

c) Material and equipment required

d) Ease of construction

e) Construction duration

f) Special construction considerations.

g) Application limitations

h) Damage during construction

The vendor will arrive on-site with all supplies and materials (except fill) loaded in one or more trucks, similar to transporting the product to a remote levee site. Fill material may be stockpiled at a designated location outside the test facility. No materials will be unloaded from the trucks until initiation of the testing protocol. A waterproof gate to the test basin will be open and small front end loaders or similar equipment way be used to aid in construction of the IFFS. When construction is complete, the gate to the test basin will be closed and no further access to the IFFS with mechanized equipment will be possible until after the overtopping test is completed.

At the completion of the tests, the vendor will disassemble the IFFS and return it to the truck(s) for removal. Suitability of the IFFS for reuse will be considered.

6.0 Hydrostatic Testing Protocol

The initial and most basic component of the STP is to evaluate the structural and hydraulic response of each IFFS to quasi-static, slowly rising hydrostatic head. The testing protocol for the hydrostatic head test will consist of flooding the basin on the river-side (or “wet” side) of the barrier or wall to the desired water level. Three water levels will be used for testing: 33-1/3%, 66-2/3%, and 95% of the height of the structure, also shown in Attachment 2. At each increment, the water level will be held at constant stage for a minimum of 22 hours. Continuous measurements will be made of seepages through the interface and the body of IFFS. Any observable movement of the IFFS will be documented and recorded on video. The wall will be measured for any lateral deflection at up to eight different locations in order to determine whether it is sound under increasing static loading. Measurements in terms of average volumetric quantity per unit of time will be used to calculate amounts of water flowing under or through the barrier. This will allow the engineer to determine how much water may become impounded, for a given duration, behind the wall.

7.0 Wave-induced Hydrodynamic Load Testing Protocol

The purpose of wave-induced dynamic load testing is to observe the structural response of the IFFS under hydrodynamic loading conditions. Typical hydrodynamics failures of temporary structures (Class C-i) include material failure or fatigue, fill loss, wall sliding or overturning, and deformation. The protocol specifies that packets of monochromatic waves with a wave period of $T = 2.0$ seconds be generated to impinge against the barrier. The wave tests will be conducted at two different calm water depths: 66.7% x h and 80% x h, where h is design water depth for the structure or 3.5 ft, whichever is lower. At 66.7% x h waves of approximately 3 in height (measured from trough to crest) will be generated continuously for a period of 7 hrs. The following day waves ranging from 7 in. to 9 in. (measured from trough to crest) will be allowed to impact the structure for 30 min in three ten minute increments. Afterwards, the wave height will range from 10 in. to 13 in. and will be allowed to impact the structure for one ten-minute increment. The water will then be brought to a level of 80% x h and the above tests will be repeated (Attachment 2). At the end of each ten minute increment of wave testing (excluding the 7 hrs of 3 in. waves), the basin will be stilled for up to 45 minutes to allow the waves to dissipate.

The seepage observations and displacement measurement as described in Section 6.0 will also be done during hydrodynamic testing. As waves grow in height, a certain portion of the wave spills over the IFFS, depending on frontal geometry, porosity, and roughness. This quantity of water can have a significant impact on the volume of seepage.

8.0 Additional Observations and Measurements of Failing Structures During Static and Dynamic Tests

Observations and measurements of any structural damage, such as material breakage, fatigue, component failure, and an estimated fill loss will be made. Three repairs of the IFFS will be allowed during the test series as will be described in Section 11. This allows an evaluation of the expediency of the repair, method used, and integrity of the repair.

9.0 Static Overtopping

Static overtopping will be caused to occur at a riverside water level equal to 100% of structure height plus one inch (IFFS height is below 3.75 feet), and the results of the overtopping with time will be recorded and evaluated. Water level on the flood (wet) side of the IFFS will be slowly raised until the depth of flow over the structure is one inch (depth of water several feet out from the structure will be approximately four inches greater than structure height). Pumps on the dry side of the IFFS will return the water to the basin to maintain a constant head in the basin and to keep the water level on the dry side of the IFFS as low as practical. This overtopping test will proceed for one hour after steady state conditions are achieved or until failure occurs. If the structure floats up the water will be raised to the appropriate elevation and the pumping will begin even though no overtopping occurs. The performance of IFFS during overtopping includes recording the movement of the structure, and observation from one or more video cameras.

10.0 Debris Impact Test

Following the overtopping test, the vendor will have the opportunity, if desired, to remove all of the water from the basins and to rebuild the IFFS to its original condition before the static, dynamic, and overtopping tests. The reconstruction procedure should be the same as the construction before static loading tests. The water level will be filled to a height of 66-2/3 % of the height of the IFFS, and the debris impact test will be performed (Attachment 3). The purpose of this test is to evaluate the structural response of the IFFS to a simulated debris load. The IFFS will be struck with two different floating logs. A log will be pulled into the IFFS using an electric winch system to provide an impact with a velocity of 7 feet per second, or about 5 miles per hour. The trajectory angle between the log and the levee will be about 75 degrees. Twelve in. and 17 in. diameter logs, each 12 feet long, will be used. The smaller log will be used first, followed by the bigger one. The movement and damage to the IFFS, if any, from the smaller log impact test will be observed before continuing to the larger log impact test. If the IFFS is leaking profusely or has experienced more than 6" permanent movement after the smaller impact log test, the bigger impact log test may not be performed. ERDC personnel will determine if it is safe to continue with the next impact log tests.

11.0 Repairs to Innovative Flood-Fight Structures

Up to a total of three minor repairs to a candidate's IFFS structure will be allowed during the three major tests (hydrostatic, hydrodynamic, and overtopping). This does not mean three repairs during each test. A minor repair is hereby defined as "a repair requiring a maximum of 30 minutes using a maximum of four men, using only materials available on site". There will be seven opportunities to make repairs, and the vendor can only make three repair attempts. The vendor must understand the STP completely before deciding the condition under which these three minor repairs will take place. The testing will not be halted during a particular test phase to make a repair. The repairs must all be made after the test or tests at one level is/are complete; this becomes more important during the dynamic testing, which is discussed below. The three types of repairs are described as follows:

11.1 Static Test/Repair Description:

During a static test, the water elevation will be raised to three different levels: 33.3% x *h*, 66.7% x *h* and 95% x *h* , and each level is maintained for a minimum of 22 hours while seepage, displacement, and material loss are recorded (Attachment 2). If the need for a minor repair develops at 33.3% x *h* or the 66.7 x *h,* the vendor may choose whether or not to perform the minor repairs before the tests proceed to the next level. If the vendor wants to make a repair after the 95% x *h* depth, safety dictates that they must wait until the water level is dropped to the 66.7% x *h* level and prior to the dynamic test to make this repair.

11.2 Dynamic Test/Repair Description:

During a dynamic test, the water level will be raised to an elevation corresponding to either 66.7% x *h* or 80% x *h*. For each water elevation, three different wave magnitudes (3 in, 7 in to 9 in, and 10 in to 13 in) will be allowed to impact the structure. The first wave height will run for seven hours, followed by the second wave height for 30 min (three 10 minute packets), followed by the third wave height for 10 minutes (one 10 minute packets) (See Attachment 2). Repairs will only be allowed after first wave height is completed and after the third wave height is completed for the elevation being tested.

11.3 Over topping Test/Repairs:

There is no need to do a minor repair after the overtopping test is completed, because the levee must be repaired to its original condition preceding the log impact test. This repair is not counted as one of the three minor repairs. A maximum of 8 hours will be allowed for this repair with no limit on the number of personnel. This repair will be the responsibility of the product vendor. The method of construction should be consistent with the original method without any modification.

11.4 Review of the three repairs allowed and when they may be performed:

In summary, three minor repairs are allowed and can be performed out of 7 different times of opportunity as shown in Table 1. After the overtopping test, vendor may need to do repair or rebuild if necessary for debris impact test. All of the repair materials must be on site to make the needed repairs in and at the times specified. Repairs must be made from like materials or repair kits for the structure.

12.0 Environmental Evaluation

Material that will be used for the construction of protective barriers will be required to have an MSDS attached if it is required by the properties of the material. The MSDS will provide information as to the chemical make-up and physical properties of the material. The Environmental Lab (EL) will review the MSDS and determine if the material will pose any environmental risk when place on or in the protective barrier. Also the EL will

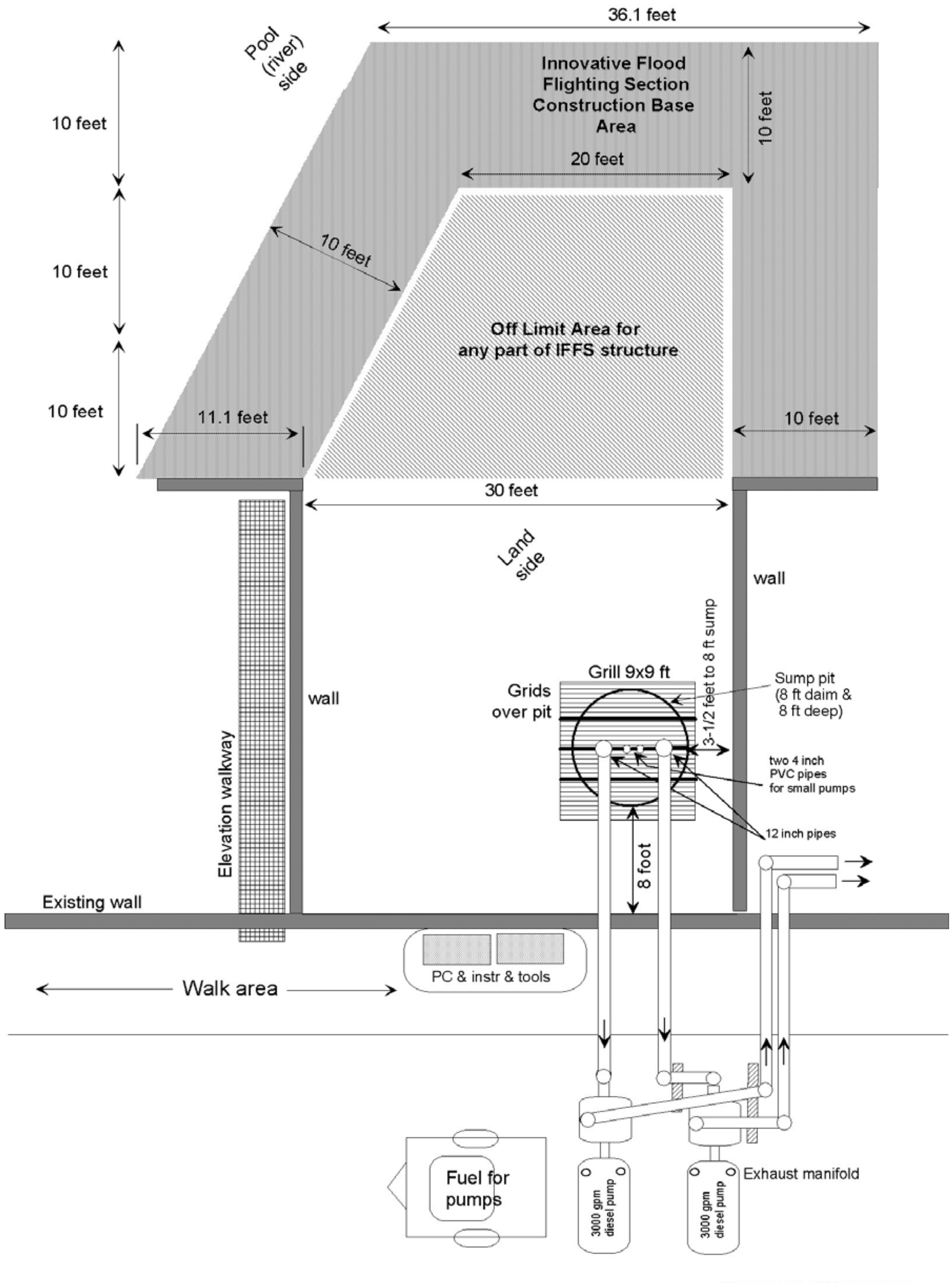
Table 1. IFFS Testing Matrix

<table>
<tr><th>Test</th><th>Condition</th><th>Repair Allowed</th></tr>
<tr><td rowspan="3">Hydro Static</td><td>33 1/3 % h, 22 hours</td><td>After 22 hours test</td></tr>
<tr><td>66 2/3 % h, 22 hours</td><td>After 22 hours test</td></tr>
<tr><td>95 % h, 22 hours</td><td>After 22 hours test, and water level lower to 66 2/3 % h</td></tr>
<tr><td rowspan="6">Hydro Dynamic</td><td>66.7% h, Low Wave,
7 hrs</td><td>After finish of 7 hrs</td></tr>
<tr><td>66.7 % h, Med Wave,
3 x 10 minutes test</td><td rowspan="2">After finish 66.7 % h,
High Wave Test</td></tr>
<tr><td>66.7 % h, High Wave,
1 x 10 minutes test</td></tr>
<tr><td>80 % h, Low Wave
7 hrs</td><td>After finish of 7 hrs</td></tr>
<tr><td>80 % h, Med Wave,
3 x 10 minutes test</td><td rowspan="2">After finish 80 % h,
High Wave test</td></tr>
<tr><td>80 % h, High Wave
1 x 10 minutes test</td></tr>
<tr><td>Overtopping</td><td>1 in overflow, 1 hours</td><td>Major repair or rebuild</td></tr>
<tr><td>Impact Debris</td><td>12 in log, 5mph
17 in log, 5 mph</td><td>Removal of all material</td></tr>
</table>

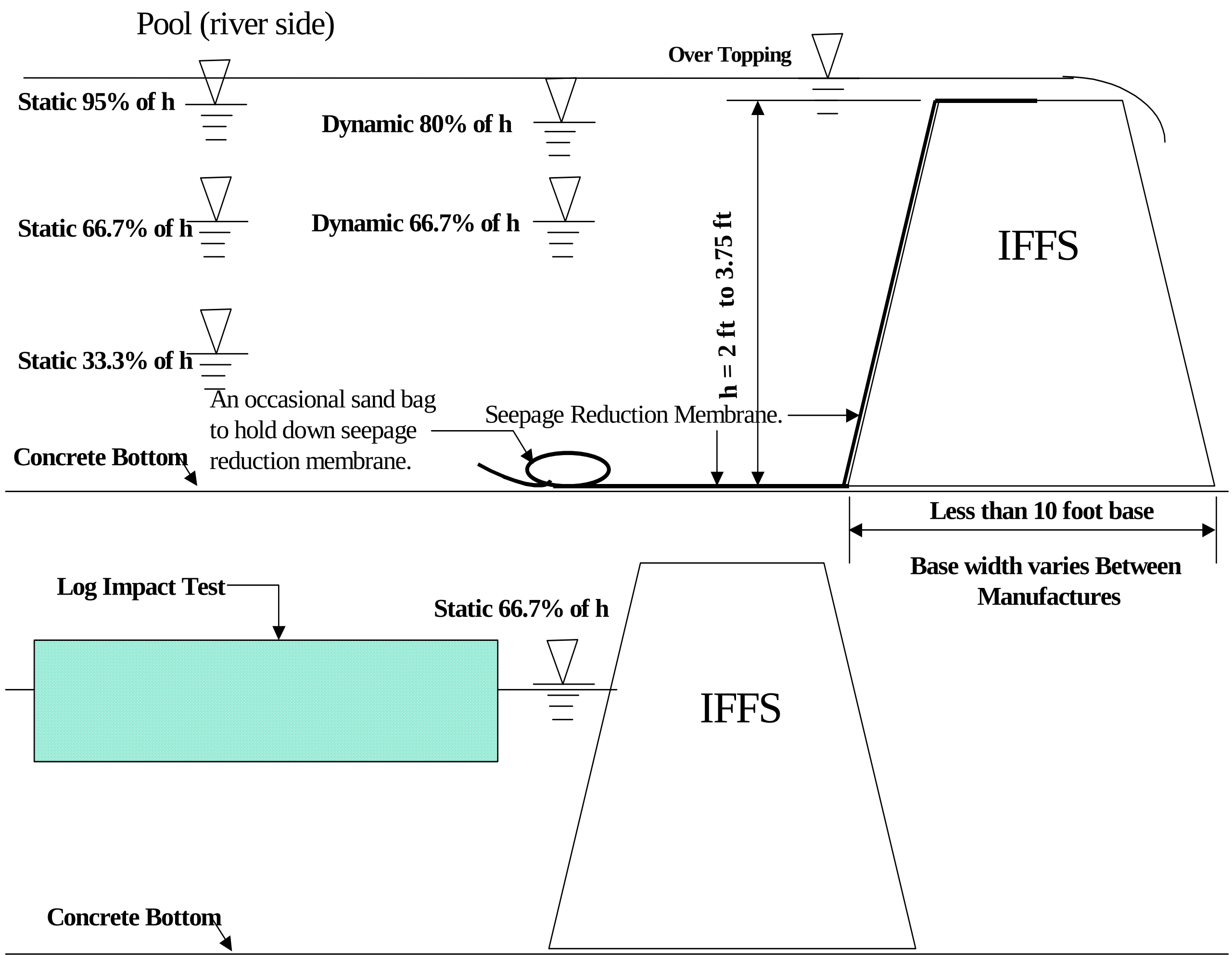
evaluate the material to determine any environmental effects the material might have if it comes in contact with certain such items as sewage, oil, debris, etc… The EL will determine special handling and disposal procedures that will need to be implemented in the case that the material is released from the barrier or if it is contaminated with other material from the environment.

13.0 Evaluation Process

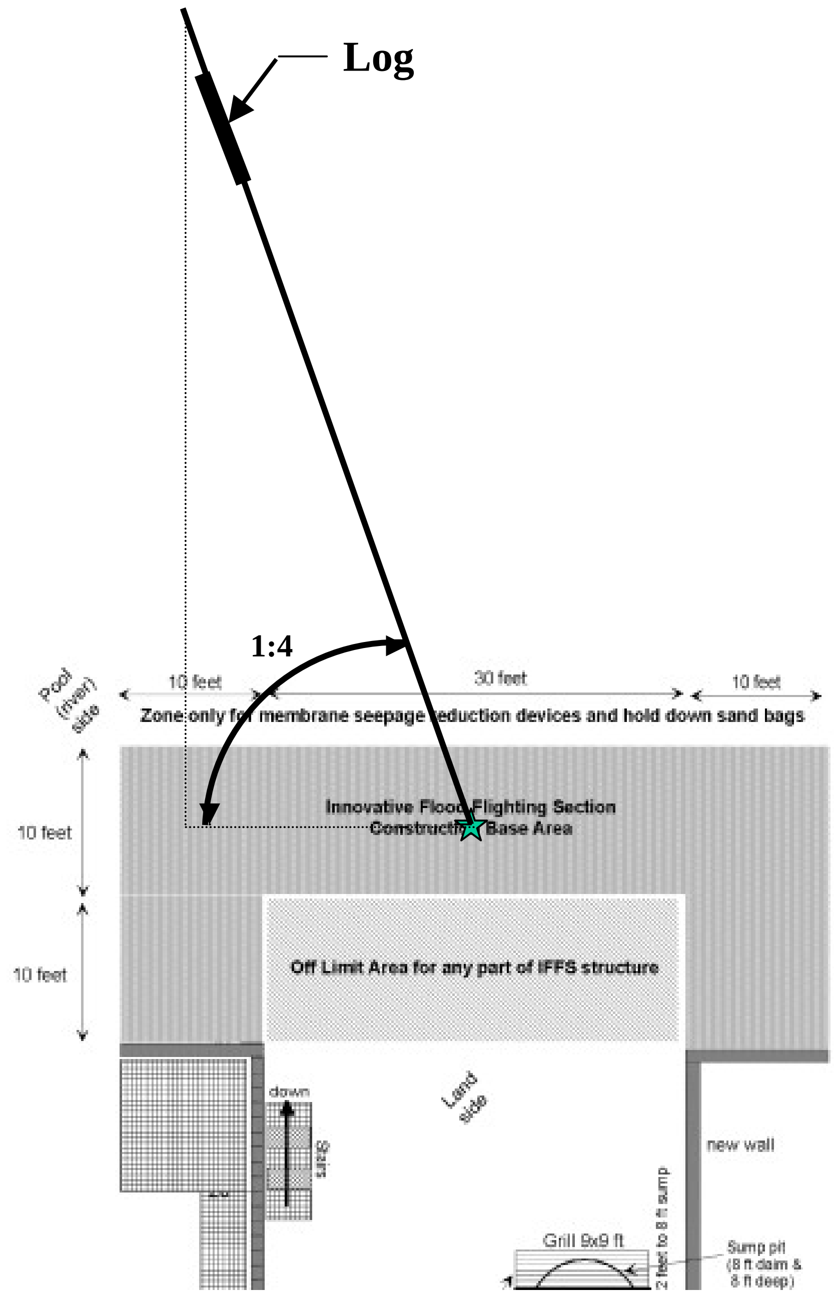
At the end of the test sequence, all measurement data will be compiled and presented in tables and charts. Photos of IFFS during construction, during test, and after test will also be presented. Quantitative results obtained for the IFFS will be compared to the results obtained with sand bag tests, which are intended as a baseline performance reference. For qualitative performance evaluations (constructability and repair difficulty), the sandbag levee performance will also be used as a reference baseline. The final evaluation report (Attachment 4) will include narrative, photographs, drawings, and tables. The report will not provide a rating of the various products, rather it will assist the field engineer in making informed decisions about the application of flood fight products to a particular application.



Attachment 1



Attachment 2



Impact angle with the horizontal is a ratio of 1:4

Attachment 3

Layout Report for Innovative Levee Test

1. Introduction
    - 1.1 Background
    - 1.2 Purpose

2. Testing Facility
    - 2.1 Plan
    - 2.2 Construction
    - 2.3 Instrumentation

3. Standard Testing Protocol
    - 3.1 Summary of Testing Protocol

4. Sand Bag Test (or technology being tested)
    - 4.1 Construction of Innovative Levee
        - 4.1.1 Plan
        - 4.1.2 Construction
        - 4.1.3 Photo
    - 4.2 Testing/Results
        - 4.2.1 Hydro Static Test
            - 4.2.1.1 Description
            - 4.2.1.2 Photo
            - 4.2.1.3 Test Results
        - 4.2.2 Hydro Dynamic Test
            - 4.2.2.1 Description
            - 4.2.2.2 Photo
            - 4.2.2.3 Test Results
        - 4.2.3 Over-topping
            - 4.2.3.1 Description
            - 4.2.3.2 Photo
            - 4.2.3.3 Test Results
        - 4.2.4 Debris Impact Test
            - 4.2.4.1 Description
            - 4.2.4.2 Photo
            - 4.2.4.3 Test Results

5. Conclusions

6. References

Attachment 4

Revision History
29 Apr 2004 Attach 1 replaced with new pit layout.